A NEW METHOD FOR STEAM TRAP TESTING

Renat Manassypov, PhD., P. Eng.
Ameresco Canada Inc., 90 Sheppard Avenue East, 7th floor, North York, M2N 6X3, Ontario, Canada,
rmanassypov@ameresco.com

Abstract

The paper presents a new method to quantify efficiency of steam traps. The steam trap efficiency is measured by loss factor calculated as the deviation degree of the bi-phase condensate heat content from the heat content of liquid condensate. Measurement of leaky and good operating trap efficiencies demonstrates capability of the method to accurately test traps in stationary or in-situ conditions.

Introduction

A common problem of steam heating systems is steam loss through faulty steam traps. Excessive energy cost is the tax imposed by inefficiency of existing methods of trap performance testing. Efficient proactive trap testing would reduce steam losses and associated costs from 20% to 1% (Collins et al. 2003).

When a trap fails in 'closed' position, the condensate propagates back to the served heat exchanger. This failure is easy to detect. When a trap fails in 'opened' position, identification of the steam loss magnitude is a challenge. Common steam leakage detection methods are based on level meters, thermo graphic trap imaging, and listening devices (Hideaki et al. 1992; Masao 1992; Turner and Nethers 1998). They provide a subjective assessment of trap condition and are not able to measure the trap steam loss. More sophisticated testing devices (Miner et al. 1983) and (Masao 1992) are intended to measure it. However, these methods require expensive installation of probes and communication wiring at every trap. Therefore, an accurate and feasible method of steam trap performance testing is needed.

New steam trap efficiency concept

Figure 1 represents a fragment of the heating steam system including a control valve, a heating coil, and a trap.

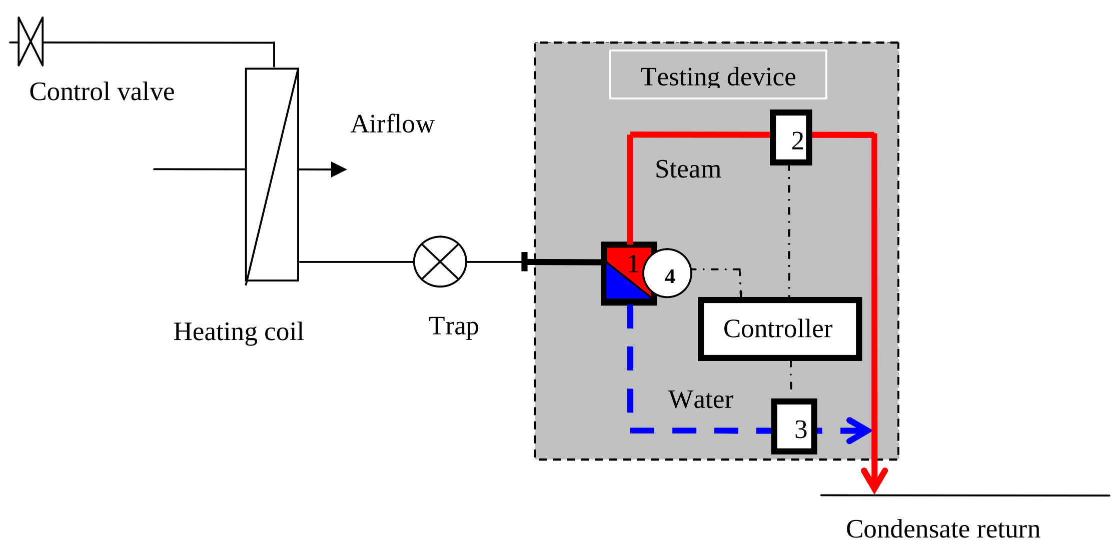

Figure 1. A steam trap testing device schematic: 1-separator, 2-steam flow rate meter, 3-water flow rate meter, 4 – temperature probe.

Steam flow modulated by the control valve heats the airflow across the heating coil and transforms to condensate reducing its enthalpy from the steam enthalpy $\mathbf{E}_{\mathbf{steam}}$ to bi-phase condensate enthalpy $\mathbf{E}_{\mathbf{actual}}$ as shown in the diagram in figure 2. If trap is operating perfectly, the condensate leaving trap would be completely liquid and have enthalpy $\mathbf{E_{cond}}$. In reality, the trap allows a certain portion of steam to pass through. The fluid downstream from the trap is a mixture of condensate and steam with enthalpy $\mathbf{E_{actual}}$ greater than $\mathbf{E_{cond}}$ located in the diagram on the line between points $\mathbf{E_{steam}}$ and $\mathbf{E_{cond}}$. The better the trap quality is, the closer $\mathbf{E_{actual}}$ to $\mathbf{E_{cond}}$ and vice versa. Hence, a ratio of the stretches 1-2 and 1-3 or $(\mathbf{E_{actual}} - \mathbf{E_{cond}})/(\mathbf{E_{steam}} - \mathbf{E_{cond}})$ is a measure of trap efficiency.

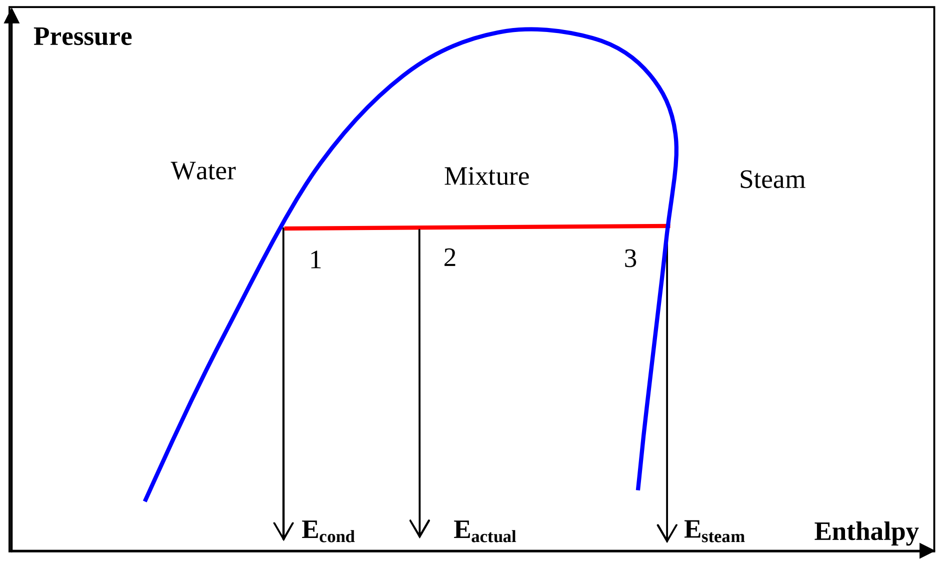

Figure 2. Schematic of the Steam/Water Enthalpy-Pressure diagram

An energy balance between the thermal energy upstream from the control valve and downstream from the trap provides same enthalpy ratio. This value named **Loss Factor** reflects trap inefficiency as a ratio between the energy loss **Energy Loss** and the heat transfer potential $\mathbf{Heat_{max}}$

$$\mathbf{LF = Energy\ Loss / Heat_{max} = (E_{actual} - E_{cond})/ (E_{steam} - E_{cond})} \qquad (1)$$

Both, the numerator and the denominator in formula (1) depend on the system arrangement and operating conditions; however, their ratio does not. Hence, the loss factor indicates steam trap performance only and presents convenient means for trap evaluation.

The thermodynamic efficiency of steam trap, as a trap ability to prevent steam loss through its orifice, would be a complement to the loss factor

$$\mathbf{Steam\ Trap\ Efficiency = 1 - LF} \qquad (2)$$

Thus, the new method of steam trap evaluation is based on introduction of the thermodynamic trap efficiency found by comparison of actual condensate enthalpy downstream from the trap against the condensate enthalpy of an ideal trap when no live steam passes through the trap.

Experimental study of the loss factor

A stationary prototype of the testing device was built based on the new loss factor method (figure 3). Schematic of the prototype in figure 1 reflects the instruments and their arrangement required to measure loss factor. The prototype was tested at McMaster University in Hamilton (Ontario).

Figure 3. The test-bench installed at McMaster University (Hamilton, Ontario)

The make up air unit heating coil heated 1085 L/s (2300 ft^3/min) of air by steam with pressure gage of 103.4 kPa (15 lb/in^2 of water gage). The condensate passed through the testing device piped downstream from the trap. The testing device (figure 1) comprised of separator 1, steam flow rate meter 2, water flow rate meter 3, and temperature probe 4. Bi-phase condensate leaving the trap was segregated into steam and water flows by the separator 1, passed through the meters and drained back to the common return pipe. A digital controller coincidently scanned all the meter and sensor readings with small time increments to calculate an instant and average loss factor by formula (1). Laptop was used to monitor the test process and to generate reports.

The water flow rate meter included a storage tank and a pump cycling on when the tank was full and off when the tank was empty. The water flow rate was calculated by the controller for the tank charge period as a ratio of the tank volume and the pump run-time.

Enthalpy $\mathbf{E_{actual}}$ was calculated as per the following formula derived from the trap energy balance:

$$\mathbf{E_{actual}} = \textbf{(Water Energy + Steam Loss Energy) / (Water Flow Rate+ Steam Loss Rate)} \quad (3)$$

To reduce the measurement error at low steam flow rates, determination of the **Steam Loss Energy** was duplicated by using additional airflow velocity and temperature probes before and after the coil.

It should be noted that the measuring instruments of the testing device and their arrangement can be designed differently while the concept remains the same.

The loss factor calculation procedure includes a series of algebraic formulas using readings of the measuring instruments (indirect measurement). Therefore, the loss factor value accumulates all the instrument uncertainties. The cumulative uncertainty of loss factor can be estimated assuming random impact of the measured variables (Schenck 1972).

Results of loss factor measurement

Series of experiments were conducted for a number of traps of different type and vintage. Two examples of the measured loss factor trends are presented in figures 4 and 5.

Figure 4 represents performance of an old ¾” diameter FT (float and thermostatic) steam trap. The instant loss factor oscillates around 17%. The associated average steam loss is 8.6 kg/h (17.8 lbs/h).

Figure 5 demonstrates performance of a new ¾” FT trap. The average loss factor is 6.8% with average steam loss of 1.5 kg/h (3.3 lbs/h).

The cumulative uncertainty of measurements is estimated at +/-12%.

The spikes at the start of trap testing and other turbulences are caused by unsteady thermal and hydraulic starting conditions and probe inaccuracy. The average loss factor trends (red lines) eliminate all the disturbances and present the actual trap performance.

A significant difference of the leaking and new trap performances illustrates that sensitivity of the new method is high enough to differentiate traps of different type and vintage.

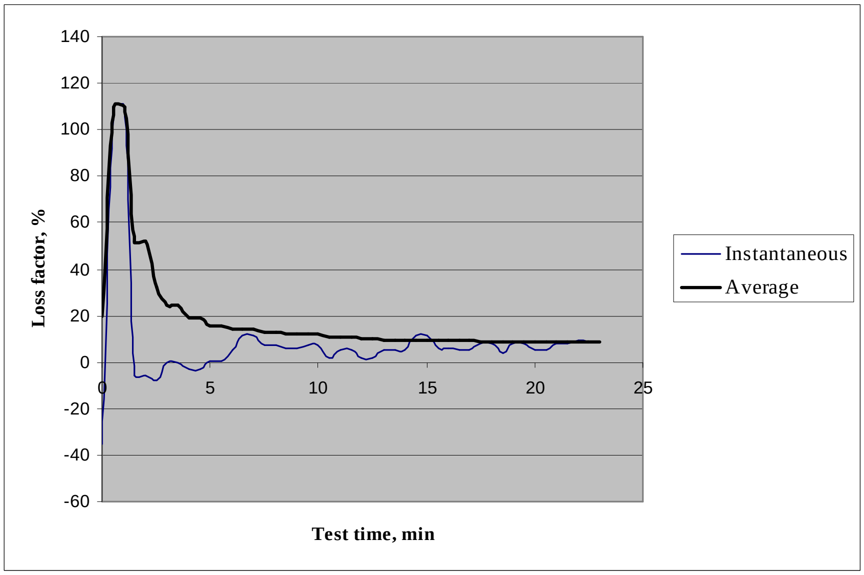

Figure 4. Loss factor trend for an old ¾" FT trap

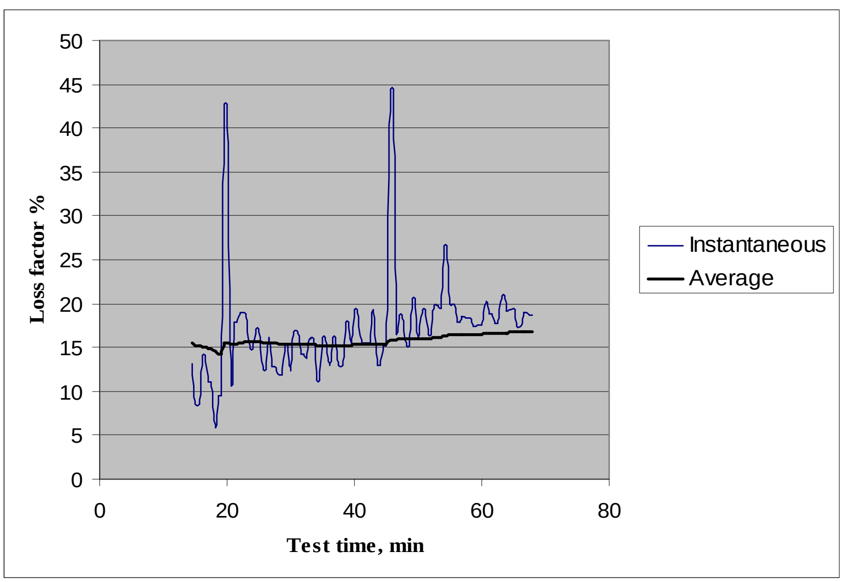

Figure 5. Loss factor trend for a new FT ¾" trap

At present only a limited number of traps were tested. A larger number of testing is required to quantify statistics on accuracy, sensitivity and other characteristics of the new method.

Anticipated average steam trap retrofit savings are about 10% of the pre-retrofit steam use. If the year-to-year pre-retrofit steam use after adjustment for weather fluctuates close or higher than the shown range, the savings verification by comparing the pre- and post-retrofit retrofit steam use may produce even a negative value (which does not make sense). In this case, verification of the steam trap retrofit savings should be done by a retrofit isolation method of verification (ASHRAE 2000).

In particular, it can be based on the existing and new trap samples measurement. Statistically valid average pre- and post-retrofit loss factors ($\mathbf{LF_{pre}}$ and $\mathbf{LF_{post}}$) can be used to calculate the steam savings as a *percent* of a normalized for weather pre-retrofit steam use as shown below

$$\textbf{Steam savings} = \textbf{Pre-Retrofit Steam Use} \times (\mathbf{LF_{pre}} - \mathbf{LF_{post}}) / [(1 - \mathbf{LF_{pre}}) \times (1 - \mathbf{LF_{post}})] \qquad (4)$$

The steam savings confidence should be calculated accounting for the sampling and indirect loss factor measurement uncertainties.

A scenario of proactive (trap-by-trap) field testing and maintenance of 600 traps by a portable version of the device for Toronto area was assessed. The comparison was done against all of the trap population being replaced every 7 years at a steam cost of 0.032 $/kg (0.014 $/lb). The proactive field testing requires addition of two union and a by-pass valves downstream from the steam traps for connection to the portable device. The piping upgrade, testing time of 0.5 hours per trap, and the portable device cost estimated at $5,000 would increase the overall maintenance cost by 12%. However, given the steam losses eliminated due to proactive testing over the 7 year span, the Savings-to-Investment Ratio (SIR) (ASHRAE. 1999) changed from 3.1 to 10.4 improving by 3 times efficiency of the retrofit investment.

Currently, only a stationary version of the device has been physically built and tested. The portable testing device research and development requires cooperation with steam equipment manufacturers, governmental agencies and other organizations.

Conclusions

- The method introduces thermodynamic steam trap efficiency as a criterion for new trap development and existing trap performance measurement.
- The steam trap efficiency is measured by loss factor calculated as the deviation degree of the bi-phase condensate heat content from the heat content of liquid condensate.
- Measurement of the trap performance as opposed to evaluation by existing testing methods reduces energy costs.
- The method provides conceptual basis to create a portable tool for proactive in-situ steam trap testing.
- The method allows for efficient verification of trap retrofit energy savings.

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